CONSTITUENTS OF THE LUNAR CRUST AT THE SERENITATIS TARGET: LEAST-SQUARES MIXING CALCULATIONS FOR APOLLO 17 POIKILITIC IMPACT MELT ROCKS. G. Ryder[1] and K. R. Stockstill [1,2], [1]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058-1113, [2]Department of Geology, Michigan State University, East Lansing, MI 48823.

Poikilitic clast-bearing impact melt rocks from the Apollo 17 landing site form a distinct chemical cluster (e.g., [1, 2]). They have been (almost) universally accepted as produced in the 3.89 Ga Serenitatis event [1-5]. We obtained chemical composition data for 3g splits of 18 samples with a range of grain size, chemistry, and collection location. The samples show variation outside of analytical error and representing interrock differences [6,7,8].

We first used numerous element-element plots, element ratio plots, and a correlation matrix to infer possible end-members of the mixes [6,7], the constituents of the crust in the target. These strongly suggest that the rocks contain noritic and troctolitic material, plus KREEP norite-gabbro that is not a single composition. Ferroan anorthosites and feldspathic granulites, commonly believed to dominate the lunar highlands, appear to be negligible constituents.

We continued by using least-squares mixing calculations to constrain the end-members, using the routine and procedures of Korotev and co-workers [9,10] For any one given composition, an infinite number of solutions could be found, but we assume that these rocks all contain the same components but in different proportions. We used numerous trial-and-error runs to search for and refine those components that are satisfactory end-members for all of the samples. We do not expect to be able to uniquely identify all components in rocks that are obviously complex mixtures [11], but to be able to characterize the main components and thus those of the crust in the Serenitatis region. There are limitations that make perfect fits to all rock compositions with a set of components impossible to contemplate:

Table 1: Components used in Tables 2,3 calculations.

	Troct 76535	Nor 15445	Dun 72415	KREEP W	KREEP X	EH Chond
SiO_2,%	43.00	48.00	40.30	48.50	47.50	35.70
TiO_2,	0.05	0.27	0.03	3.80	2.10	0.08
Al_2O_3	20.73	23.00	1.30	16.00	16.50	1.53
FeO	5.00	3.90	11.70	11.00	13.00	37.40
MnO	0.07	0.15	0.07	0.13	0.14	0.28
MgO	19.09	10.20	44.80	9.00	7.50	17.60
CaO	11.41	12.80	1.10	10.50	11.00	1.19
Na_2O	0.23	0.32	0.13	0.80	1.00	0.92
K_2O	0.03	0.07	0.00	0.60	0.30	0.10
Sc ppm	1.94	7.12	4.30	30.00	25.00	5.70
Cr	730	1710	2300	1700	1500	3150
Co	28	10	55	9	9	840
Ni	44	11	200	70	70	17500
Sr	114	130	10	270	230	7
Zr	17	115	3	750	550	5
Ba	33	62	4	750	600	3
La	1.51	4.02	0.15	63.00	55.00	0.24
Sm	0.61	1.81	0.08	30.00	25.00	0.14
Eu	0.70	0.87	0.06	3.00	3.00	0.05
Yb	0.56	1.72	0.07	22.00	18.50	0.16
Hf	0.41	1.36	0.10	23.80	20.00	0.14
Th	0.19	0.82	0.15	9.90	8.90	0.03
U	0.05	0.16	0.01	2.90	2.90	0.01
Ir ppb	0.01	0.02	1.60	0.01	0.01	565.00

1) Experimental uncertainties and errors in the rock analyses. 2) Improbability that the melted target or the added fragmental material consist of a small number of well-defined components. 3) Volatile loss, e.g. Na, not accounted for in a purely mechanical mixing simulation. 4) Crystallization effects that fractionate and even at the 3g scale might be effective in distorting a mechanical mixing simulation (e.g Ni and Co; see accompanying abstract by Ryder).

We addressed some of these limitations with artificial components and mixes, adding uncertainties to the analyses and to the components, and adding and removing components. The purpose was to see how much deviation from a "reality" a calculation can include before nothing of substance remains. For acceptable least-squares results, one normally requires a sum of components close to 100%, all positive components, and a reduced chi-square (χ^2/v) of about 1 (e.g. [9,10,]). Our essential conclusions are that it is 1) very difficult to obtain reasonable results when the components are poorly constrained or wrong, and 2) becomes very easy to lose all information on a component less than 5% or so unless it some very distinctive characteristic. However, these calculations gave us confidence that if good results are obtained, there is probably some correspondence of the hypothetical components with reality.

We made many calculations on the Apollo 17 poikilitic rock analyses using common lunar highlands pristine (igneous) rocks, KREEP rocks, and meteoritic components as end-members. For this series of runs, those using anorthosite and granulite as components had large negative components and χ^2/v in the thousands, completely unacceptable.

We then attempted to close in on the real components, making many calculations using varied norites, varied troctolites, and KREEP components. From these results, most of which were poor, we selected and modified the components to obtain better fits. For our most recent and most successful run, we used the 6 components shown in Table 1, with results shown in Table 2. Where dunite is given as 0%, the calculations initially gave small negative numbers for dunite and were re-run omitting dunite. The sum of the components in all cases lies between 98.3 and 100.3 and all components are positive. The χ^2/v is between 1.2 and 5.8 for all but three samples. These are obviously not perfect results, but given the limitations above, they are highly suggestive that components very similar to these must dominate these rocks.

For illustration, the actual results for three samples are shown in Table 3. K_2O is a common problem, and may reflect inadequate end-member selections or analytical problems. Zr, Sr, and Ba, none well-analyzed by our techniques, are commonly discrepant, as are in some cases Th and U. Most of these suggest that there is more variation in the KREEP components in the target than is accounted for by our two hypothetical ones. Commonly discrepant are Ni and Co. We have had little success in exactly matching these

elements, perhaps because of redistributions. We place Ni and Co in the KREEP only because they are NOT in the pristine components; adjustments will be made in future runs. The KREEP components have low SiO2 abundances, and might be already well-mixed, e.g. olivine with KREEP. Unravelling these components is essential to understanding the nature and origin of the crust in the Serenitatis region.

Table 2. Results of least-squares mixing calculations for 22 analyses of Apollo 17 poikilitic rocks

	72315	72395	72435	72535	72539	72549	72736	73155	73216	73275	76015a
Troctolite%	19.7	7.6	24.0	13.7	30.4	32.8	13.6	22.8	26.6	21.4	29.2
Norite%	33.2	39.9	16.1	33.6	15.7	12.0	35.8	8.5	18.8	28.3	14.6
Dunite%	0.0	6.2	2.2	4.6	0.0	0.7	6.0	0.0	0.2	1.2	0.0
KREEPW%	23.1	7.9	23.6	19.6	24.7	35.0	19.4	42.5	18.6	19.8	15.2
KREEPX%	22.6	36.7	31.5	25.9	26.7	17.0	22.0	22.8	33.5	27.6	39.2
EH Chon%	1.0	1.6	0.9	1.3	2.1	1.5	1.6	1.2	1.5	2.0	0.6
Sum	**99.6**	**99.9**	**98.3**	**98.7**	**99.6**	**99.0**	**98.4**	**97.8**	**99.2**	**100.3**	**98.8**
χ^2/v	**12.0**	**8.0**	**1.2**	**3.2**	**2.8**	**2.5**	**4.3**	**18.1**	**2.3**	**4.7**	**3.0**
KW/(KX+KW)	0.5	0.2	0.4	0.4	0.5	0.7	0.5	0.7	0.4	0.4	0.3
K%	45.9	44.6	56.1	46.1	51.6	52.5	42.1	66.8	52.5	47.3	55.0
	76015b	**76215a**	**76215b**	**76295a**	**76295b**	**76315a**	**76315b**	**77035**	**77075**	**77135**	**77539**
Troctolite%	29.3	33.5	35.5	17.0	17.2	25.5	25.5	25.3	32.6	25.4	22.4
Norite%	14.1	15.7	13.5	19.1	19.4	21.5	20.1	26.5	11.4	16.7	21.2
Dunite%	0.0	1.3	0.9	0.0	0.0	1.0	0.9	18.7	1.9	0.0	5.9
KREEPW%	14.5	10.6	9.2	20.0	18.9	12.4	13.8	16.2	15.3	12.3	12.5
KREEPX%	40.6	37.9	39.6	41.7	42.0	38.9	38.6	12.0	37.8	43.1	37.3
EH Chon%	0.3	1.3	1.4	1.0	1.2	0.6	1.5	1.6	1.0	2.1	0.3
Sum	**98.8**	**100.3**	**100.1**	**98.8**	**98.7**	**99.9**	**100.4**	**100.3**	**100.0**	**99.6**	**99.7**
χ^2/v	**3.4**	**4.6**	**3.2**	**5.8**	**5.2**	**1.8**	**3.0**	**1.6**	**2.4**	**4.8**	**4.3**
KW/(KX+KW)	0.3	0.2	0.2	0.3	0.3	0.2	0.3	0.6	0.3	0.2	0.3
K%	55.8	48.4	48.8	62.4	61.7	51.4	52.2	28.1	53.1	55.6	50.0

χ^2/v = reduced chi-square. KW/(KW+KX) = proportion of KREEPW to total KREEP components. K% = percentage of KREEP in Sum.

Table 3. Examples of results of calculations for least-squares mixing using components in Table 1.

	73215	χ^2/v = 12.0			77539	χ^2/v = 4.3			72435	χ^2/v = 1.2		
	Obs.	**Calc.**	**Abs.Diff.**	**%Diff.**	**Obs.**	**Calc.**	**Abs.Diff.**	**%Diff.**	**Obs.**	**Calc.**	**Abs.Diff.**	**%Diff.**
SiO_2 wt.%	46.91	46.50	-0.41	-0.87	46.03	46.08	0.05	0.11	45.55	45.65	0.10	0.22
TiO_2	1.45	1.45	0.01	0.35	1.51	1.33	**-0.18**	**-11.99**	1.64	1.62	-0.02	-1.52
Al_2O_3	18.66	19.14	0.48	2.59	17.38	17.75	0.36	2.10	17.77	17.69	-0.08	-0.45
FeO	7.89	8.08	0.19	2.38	8.54	8.99	**0.45**	**5.25**	8.79	9.10	0.31	3.54
MnO	0.12	0.13	**0.01**	**4.96**	0.12	0.12	**0.01**	**7.83**	0.12	0.12	0.00	2.54
MgO	10.99	11.00	0.01	0.12	13.56	13.19	-0.38	-2.76	12.19	11.97	-0.22	-1.80
CaO	11.06	11.41	0.35	3.13	10.79	10.75	-0.04	-0.35	10.66	10.78	0.12	1.09
Na_2O	0.59	0.57	-0.02	-3.22	0.65	0.60	**-0.05**	**-6.94**	0.64	0.62	-0.02	-2.82
K_2O	0.31	0.24	**-0.08**	**-25.16**	0.16	0.21	**0.05**	**30.00**	0.24	0.26	**0.02**	**8.51**
Sc ppm	15.63	15.36	-0.27	-1.71	15.16	15.29	0.13	0.88	17.57	16.71	**-0.86**	**-4.91**
Cr	1317.00	1464.00	**147.00**	**11.16**	1408.00	1445.00	37.00	2.63	1405.00	1401.00	-4.00	-0.28
Co	23.38	21.09	**-2.29**	**-9.81**	15.30	18.88	**3.58**	**23.40**	22.13	21.73	-0.40	-1.81
Ni	212.00	217.52	5.52	2.60	135.00	116.73	**-18.27**	**-13.53**	213.00	207.00	-6.00	-2.82
Sr	193.00	186.57	-6.43	-3.33	189.00	177.00	**-12.00**	**-6.35**	186.00	188.00	2.00	1.08
Zr	336.00	339.00	3.00	0.89	396.00	327.00	**-69.00**	**-17.42**	404.00	373.00	**-31.00**	**-7.67**
Ba	386.00	331.00	**-55.00**	**-14.25**	321.00	336.00	**15.00**	**4.67**	352.00	379.00	**27.00**	**7.67**
La	27.77	28.62	0.85	3.05	29.36	29.59	0.23	0.78	33.27	33.20	-0.07	-0.20
Sm	13.19	13.30	0.11	0.86	13.54	13.60	0.06	0.47	15.40	15.39	-0.01	-0.05
Eu	1.86	1.80	-0.06	-3.28	1.91	1.84	-0.07	-3.46	1.97	1.96	-0.01	-0.36
Yb	10.15	9.61	**-0.55**	**-5.37**	9.74	9.71	-0.03	-0.29	10.67	11.00	0.33	3.09
Hf	11.05	10.14	**-0.91**	**-8.23**	11.06	10.35	**-0.71**	**-6.42**	11.90	11.73	-0.17	-1.43
Th	5.55	4.56	**-0.99**	**-17.80**	4.60	4.73	0.13	2.89	5.15	5.27	0.11	2.23
U	1.51	1.34	**-0.17**	**-11.06**	1.27	1.44	**0.17**	**13.46**	1.57	1.58	0.01	0.76
Ir ppb	5.50	5.63	0.13	2.29	2.40	1.97	**-0.43**	**-17.79**	4.80	4.94	0.14	2.92

References: [1] Ryder G. (1996) LPSC XXVII, 1121. [2] Dalrymple G.B. et al.. (1996) JGR (Planets) 101, 26069. [3] Spudis P.D. et al.. (1981) Proc. Conf. Multi-Ring Basin, 133. [4] Simonds (1975) PLSC6, 641. [5] Spudis P.D. (1993) The Geology of Multi-Ring Impact Basins. Camb Uni Pr, 263 pp. [6] Stockstill K.R. et al. (1995) GSA Abs. Progs. 27, A-290. [7] Ryder G. et al.. (1996) Met. Plan. Sci. 31, A-121. [8] Ryder G. et al.. (1995) LPS XXVI, 1209. [9] Korotev R.L. et al..(1992) PLPS 22, 275. [10] Korotev et al. (1995) JGR (Planets) 100, 14403. [11] Ryder et al. (in press) GCA.